

THE TWO MODES OF VISUAL PROCESSING:
IMPLICATIONS FOR SPATIAL ORIENTATION

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The concept of two visual systems or two modes of processing visual information (1, 2), although in some respects an oversimplification, is nevertheless helpful in evaluating the role of vision in spatial orientation. The two modes are:

A FOCAL mode which in general answers the question of "what," i.e., what is the nature of the object being examined? What is its form? What patterns does it contain? Most studies of vision, particularly in relation to performance evaluation, have been concerned exclusively with focal vision. The familiar capital letter opto-type is the most widely used test of focal vision.

An AMBIENT mode which is concerned with the question of "where," i.e., where is the observer in space? Is the observer or the environment moving?

Focal and ambient vision differ along a number of dimensions. Specifically:

1. The focal mode is almost, if not exclusively, visual while the ambient mode acts in concert with the vestibular, somatosensory, and auditory senses to subserve spatial orientation, posture, and gaze stability. In effect, we have a focal visual mode which is predominantly visual and an ambient system to which vision contributes along with vestibular and somatosensory inputs.

2. Object recognition by the focal mode is subserved by the full range of spatial frequencies, whereas the ambient mode is adequately activated by low spatial frequencies typically stimulating large areas of the visual field.

3. Adequate luminance and lack of refractive error are critical for some aspects of focal vision (for example, foveal acuity), but play a much less important role in ambient vision. The low spatial frequencies subserving ambient vision are less sensitive to degradation of retinal image quality by refractive error or by reduction of illumination.

4. As would be expected in terms of spatial frequency, focal vision is less efficient in the peripheral visual field. Although ambient functions are less efficient if restricted to a small area of the periphery as compared with central vision, unlike focal vision, ambient functions are typically optimized the larger the area of the visual field stimulated.

5. Focal vision typically involves attention while ambient visual functions are more reflexive in nature. Reading while walking illustrates the fact that although attention is dominated by the focal-mediated reading task, spatial orientation is adequately maintained by the ambient mode with little or no conscious effort.

When analysing the contribution of vision to spatial orientation, it is important to consider the characteristics of ambient vision and its interaction with the vestibular and somatosensory inputs. Some examples include:

SPATIAL DISORIENTATION/MOTION SICKNESS. In recent years, the importance of sensory mismatch within the ambient system in the etiology of spatial disorientation and motion sickness has been demonstrated. Whenever the multiloop sensory inputs differ from the habitual pattern of previous stimulation, the conflicting and incompatible signals to the gaze stability and spatial orientation systems result in disorientation and/or gastric symptoms (3).

VEHICLE GUIDANCE/NIGHT DRIVING. The two modes can be functionally dissociated. For example, spatial orientation is adequate in the absence of the ability to recognise objects due to refractive error or reduction of luminance level. We have suggested that this selective degradation is a factor in nighttime driving accidents. Vehicle guidance is a dual task: steering relies on ambient vision while recognition of signs and hazards is mediated by the focal mode. At night, ambient vision functions as well as in daylight. However, since the drivers' self-confidence derives from the ability to steer the vehicle, and they are not aware of reduction in the ability to recognise hazards with the degraded focal system, nighttime driving speeds are often too fast to permit a timely response to infrequent and unexpected hazards on the roadway (4).

VISUAL NARROWING UNDER STRESS/CORTICAL BRAIN DAMAGE. The two modes can be dissociated in other situations as well. Under various kinds of stressors, reaction time to objects imaged in the peripheral visual field may be increased or the objects may not be detected. This phenomenon is referred to as "tunnel" vision or narrowing of the visual field (5). Even more dramatically, studies of patients with cortical brain damage have demonstrated that spatial orientation can be carried out completely without awareness when the stimuli are imaged on areas of the visual field which are scotomatous as tested by conventional perimetry; i.e., "blindsight" (6). Thus, focal and ambient vision can be dissociated either by brain damage or by the nature of the attentive demands in certain tasks such as occur when driving a vehicle. A possible implication of functional dissociation in normals is that the phenomenon of visual narrowing could result from the concentration of focal vision due to shifts of attention. On the other hand, ambient vision which does not require attention, is probably unaffected by attentional narrowing. A critical factor is that traditional static perimetry makes use of a focal task requiring attention which can be redirected by the observer. Ambient vision, in contrast, is reflexive and therefore not susceptible to modification by attention shifts. Whether selective degradation of focal vision, while ambient function remains intact, is also characteristic of visual narrowing resulting from stressors such as hypoxia or excessive gravitational forces has not yet been determined.

Because both focal and ambient vision are critical in human performance, it is important that visual tests be employed which are sensitive to both functions. Most tests of vision in current use evaluate only focal vision and are therefore of limited usefulness in predicting performance in many situations, particularly those involving spatial orientation.

AIRCRAFT INSTRUMENTATION. Because ambient visual functions are reflexive, they present potential advantages in displaying orientation information in aircraft as compared with symbolic displays which involve learning and interpretation (7). As pointed out by Head (8), processes which require higher levels of information processing are more vulnerable to loss during stress than reflexive functions. This concept is incorporated in the Malcolm Peripheral Vision Horizon Display which provides a wide angle artificial horizon in order to more adequately stimulate the ambient system (9).

INTERACTION BETWEEN FOCAL VISION AND THE AMBIENT SYSTEM

Although the ambient system can function adequately in the absence of focal vision, focal vision is not independent of disturbances of the ambient system. Disruption of gaze stability mechanisms, either vestibular or optokinetic when the head is in motion, results in retinal image motion. Such inappropriate image movement lowers contrast and reduces spatial resolution (dynamic visual acuity). Another consequence of ambient dysfunction is disorientation and/or motion sickness. Gastric symptoms associated with intersensory mismatch within the ambient system are attention-demanding and interfere with object recognition and visually mediated judgments. Illusory object or self-motion frequently occurs when, in order to compensate for ambient dysfunction, the pursuit system is activated to preserve gaze stability (10). Such illusory motion is difficult if not impossible to distinguish from true object or self motion.

IMPLICATIONS FOR FUTURE RESEARCH

In order to evaluate and predict performance in demanding situations, tests of both focal and ambient function are necessary. Because focal vision has been emphasized historically, a number of reliable techniques are available to assess spatial resolution, visual fields, color vision, depth perception, etc. Significant improvements in some of these have recently been developed, in particular the contrast sensitivity function (11). Some tests of ambient function are available but they are not as comprehensive. Although we have excellent techniques for assessing vestibular sensitivity, the integrated function of the components of the ambient system has not been extensively investigated. Quantitative evaluation of body sway has shown considerable promise in clinical diagnosis and represents a potentially powerful methodology in the performance context (12). Individual differences in illusory self-motion (vection) and induced tilt are marked, but their origin and significance are unknown. Sensitive measures of optokinetic nystagmus are in extensive clinical use but, with few exceptions, the visual parameters have not been studied in detail. Questions such as the relative contribution of various areas of the visual field (particularly central vs. peripheral), and the role of spatial frequency, contour extent, and contrast remain to be resolved.

In many respects, the ambient system and in particular, its visual component represents an uncharted frontier with important implications for psychophysics, medicine, and human engineering. It is perhaps appropriate that this meeting has been scheduled in the middle of a vast desert. Let us hope that this gathering represents an oasis which will inspire further study of this hitherto neglected system.

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